A Very Low Power, Highly Integrated Multichannel Scaler

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Overview

NASA-funded efforts have led to the development of several photon counting multichannel scaler (MCS) cards and systems;

NASA SBIR-Phase I & II efforts have resulted in deliverables serving numerous NASA as well as non-NASA lidar programs;

Current ESTO-funded Phase-III efforts are allowing us to help migrate existing systems to newer UAV platforms.

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Multichannel Scaler Basics

- An MCS is a high-speed counter and accumulator designed to count, histogram, and accumulate over a specified number of iterations.
- On each laser shot, returned pulses are counted and binned. On each subsequent shot, pulses are accumulated into their given bin until the number of accumulations has been attained. This is the integration cycle.
- Parameters such as # of bins, Bin dwell time, and # of iterations in an integration cycle are software controlled.
- The accumulation process allows the signal-to-noise ratio to reach acceptable levels.
- Data is transferred after each integration cycle.
- Dead time between bins or during data transfer is undesirable.
- Faster count rates and smaller bin sizes provide greater resolution.
- Multiple detector inputs allow for multi-spectral data acquisition.

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Goals & Objectives

Develop a photon counting multichannel scaler (MCS) hardware with the following features:

- Multiple detector inputs
- Compact size
- Low power
- Highly reliable
- Remotely deployable (embedded airborne or fielded)
- No dead time between bins
- No dead time during PC transfers
- Resolution / accuracy suited for atmospheric studies
- Parameters controllable via software
- Easily customizable for different specific project needs

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Relevance To NASA

- Numerous photon-counting based lidar systems would benefit from a small, rugged, multi-detector input photon counting card.
- Power, size, and performance need to be optimized for NASA's embedded portable applications.
- Data loss during data transmission to PC is unacceptable for NASA's lidar programs; some off-the-shelf products unable to guarantee continuous operation.
- Most of NASA's lidar programs need some customization; off-the-shelf products are unable to provide user reconfigurability.

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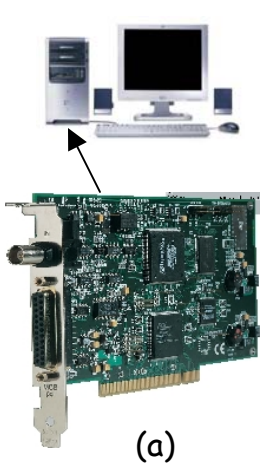
MCS – Market Sample

Off the shelf components (at time of SBIR start) either too power-hungry, too large, or not suited for remote, rugged environments



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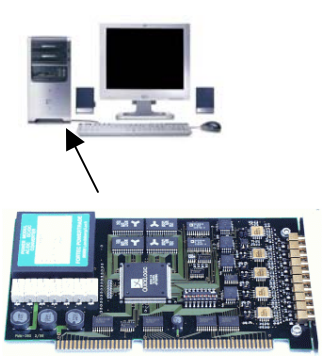

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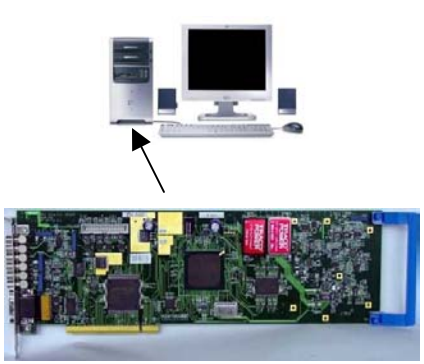

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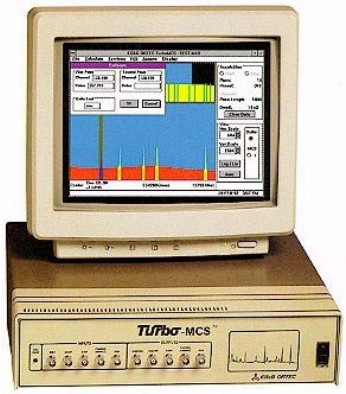


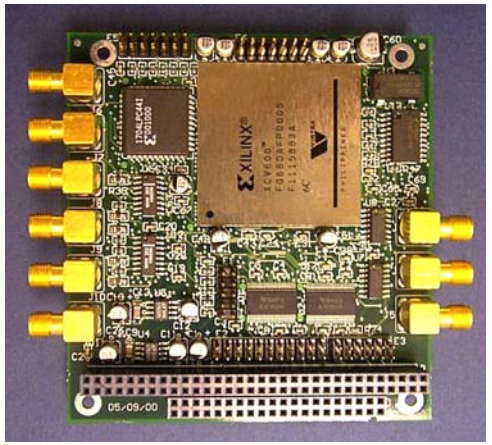
(d)

(e)

(a) MCS-PCI (EG&G / Ortec / Perkin Elmer): PCI plug-in (requires PC), single detector input, 4.2 W
(b) PMM-328 (Becker-Hickl): ISA plug-in (requires PC), 8-detector inputs, 8 W
(c) MCA-3 (FastComTec): PCI plug-in (requires PC), 2-detector inputs, 8 W
(d) Turbo-MCS (EG&G / Ortec / Perkin Elmer): Desktop, single detector input, 115 VAC power
(e) SR430 (Stanford Research): Desktop, single detector input, 60 W, 115 VAC Power

Progression – PRE-SBIR: AMCS-5

- AMCS-5 card development
  - Funded by Dr. Matt McGill (for CPL) and Dr. Jonathan Rall (for AGO Lidar).
  - Features:
    - PC/104 (3.6" x 3.8") form factor
    - 5 detector inputs
    - Total power: 2.2W
    - 4k useable bins per detector channel
    - 16-bit counter bins
    - Hardware counting & integration
    - Remotely deployable
    - No data loss during transfer
    - 9.4 meter resolution
    - Common sync pulse input
    - Pulse outputs (A/D & energy monitor)
    - Industrial temperature grade
    - FPGA-based design allows for customization



AMCS-5 Card (Front & Back)

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Progression – SBIR Phase-I: AMCS-USB / +

- AMCS-USB card development
  - Funded by NASA Phase-I SBIR
  - Features:
    - Small (4.2" x 4.2") form factor
    - USB 1.1 interface (for convenient PC analysis)
    - Total power: 3.2W
    - Integrated memory in single chip allows for various memory architectures
    - 4 detector inputs (AMCS-USB) or 8 detector inputs (AMCS-USB+)
    - 4k useable bins per detector channel (default)
    - 16-bit counter bins (default)
    - Hardware counting & integration
    - No data loss during transfer
    - 7.5 meter resolution
    - Common sync pulse input
    - Pulse outputs (A/D & energy monitor)
    - Industrial temperature grade
    - FPGA-based design allows for customization

AMCS-USB Card

AMCS-USB+ Card

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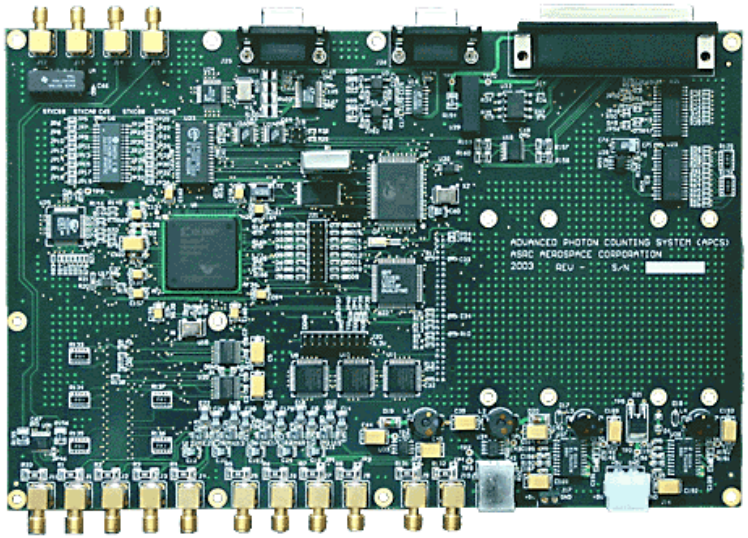
Progression – SBIR Phase-II: APCS

- APCS (Advanced Photon Counting System) card development
  - Funded by NASA Phase-II SBIR
  - Features:
    - System-level features on a single card
    - 6.5" x 10" form factor
    - USB 2.0 high-speed interface & microcontroller
    - Total Power: 4.5W
    - 10 detector inputs
    - 4k useable bins per detector channel (default)
    - 16-bit counter bins (default)
    - Hardware counting & integration
    - No data loss during transfer
    - 6 meter resolution
    - EEPROM for settings; Automatic startup
    - Common sync pulse input
    - 10 Pulse outputs
    - Integrated memory in single chip allows for various memory architectures
    - Direct 2.5" solid state or mechanical hard drive mounting & storage (for remote deployment)
    - Daughtercard connector for planned 1 GHz, 5 detector input front-end
    - Two serial port TX / RX for incoming data streams or for quicklook data
    - On-card housekeeping A/D converter for 16 analog inputs
    - On-card real-time clock for data time tagging
    - FPGA-based design allows for customization



APCS Card

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Card Summary / Comparison

	AMCS-5	AMCS-USB	AMCS-USB+	APCS
Interface	PC/104	USB 1.1	USB 1.1	USB 2.0
Size	3.6" x 3.8"	4.2" x 4.2"	4.2" x 4.2"	6.5" x 10"
# of channels	5	4	8	10
Power (Total / Per Channel)	2.5 W / 0.5 W	3.2 W / 0.80 W	6.2 W / 0.77 W	4.5 W / 0.45 W
Min Bin Size (ns / meters)	62.5 ns / 9.4 m	50 ns / 7.5 m	50 ns / 7.5 m	40 ns / 6 m
Count Rate (Nominal/Constrained)	45.5 MHz / 100 MHz	45.5 MHz / 100 MHz	45.5 MHz / 100 MHz	45.5 MHz / 115 MHz
Timebase	112 MHz (8.93 MHz)	100 MHz (10 ns)	100 MHz (10 ns)	125 MHz (8 ns)
Double-bufferred memory	Yes	Yes	Yes	Yes
# of output discretes	3	3	3	10
2.5" hard drive connector and direct data storage / readout	No	No	No	Yes
Serial ports, real-time clock, and Housekeeping A/D converter	No	No	No	Yes
1 GHz daughtercard expansion	No	No	No	Yes
Software drivers / example	Yes	Yes	Yes	Yes

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NASA Programs: Cloud Physics Lidar (CPL)

- CPL is an airborne instrument (flown on the ER-2 & WB-57; plans for UAV) flying at an altitude of approx. 20 kM (65,000 feet)
- Provides high resolution profiles of cloud, smoke & aerosol layers
  - Layer optical depth
  - Extinction profile
  - Depolarization ratio (molecular phase of clouds)
- Provides data in three wavelengths:
  355 nm, 532 nm, 1064 nm
- Raw data collected every 1/10th second
  - 5 kHz laser PRF; 500 accumulations
  - 1 second data products produced
- Data used with other aircraft instrument data as well as satellite underpass data for validation

ER-2 Aircraft

CPL Data System

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NASA Programs: Cloud Physics Lidar (CPL) – cont.

- CPL flies above > 94% of Earth's atmosphere thereby serving as a satellite instrument validation tool

- CPL has participated in at least 8 campaigns since 2000

Campaign	Full Name	Location	Year	Aircraft	MCS Card	Purpose
SAFARI 2000	Southern African Regional Science Initiative	Africa	2000	ER-2	AMCS-5	Study the climatology of Africa with emphasis on biomass burning & emissions
CRYSTAL-FACE	Cirrus Regional Study of Tropical Anvils and Cirrus Layer - Florida Area Cirrus Experiment	Florida	2002	ER-2	AMCS-5	Investigate tropical cirrus cloud systems
TX-2002	Terra-aqua eXperiment 2002	Texas	2002	ER-2	AMCS-5	Assess data products of the MODIS and AIRS instruments on the Terra and Aqua satellites
THORPEX PTOST	The Observing System Research and Predictability Experiment	Hawaii	2003	ER-2	AMCS-5	Improve short and long term weather forecasting
GLAS Cal/Val	Geoscience Laser Altimeter System	California	2003	ER-2	AMCS-5	Validate and calibrate atmospheric lidar channels of GLAS onboard the ICESat satellite
THORPEX ATOST	The Observing System Research and Predictability Experiment	Maine	2004	ER-2	AMCS-5	Improve short and long term weather forecasting
AVE #1	Aura Validation Experiment	Texas	2004	WB-57	APCS	Validate and calibrate Aura measurements
AVE #2	Aura Validation Experiment	Texas	2005	WB-57	APCS	Validate and calibrate Aura measurements

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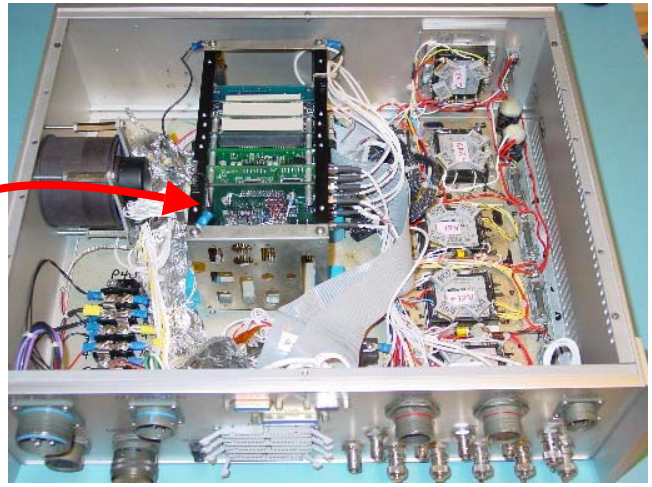
NASA Programs: Cloud Physics Lidar (CPL) – cont.

- CPL Data System – 2 flavors:
  - AMCS-5 PC/104 Stack System ("Old")
    - 7 Cards: CPU, AMCS-5, 2 A/Ds, Serial Comm, Misc circuitry, and Video (for ground use only).
    - Windows-based system not ideal for remotely deployed system due to lack of specific OS controls.
  - APCS Single Card System ("New")
    - CPL needs were specifically addressed when designing card such that functions of 6 cards of the original PC/104 stack are now performed by one circuit card.
    - Modular power system, less interconnects, and higher reliability
    - Optimized embedded firmware improves operational reliability.

AMCS-5 Card



AMCS-5 PC/104-Based CPL Data System

APCS Card

APCS-Based CPL Data System

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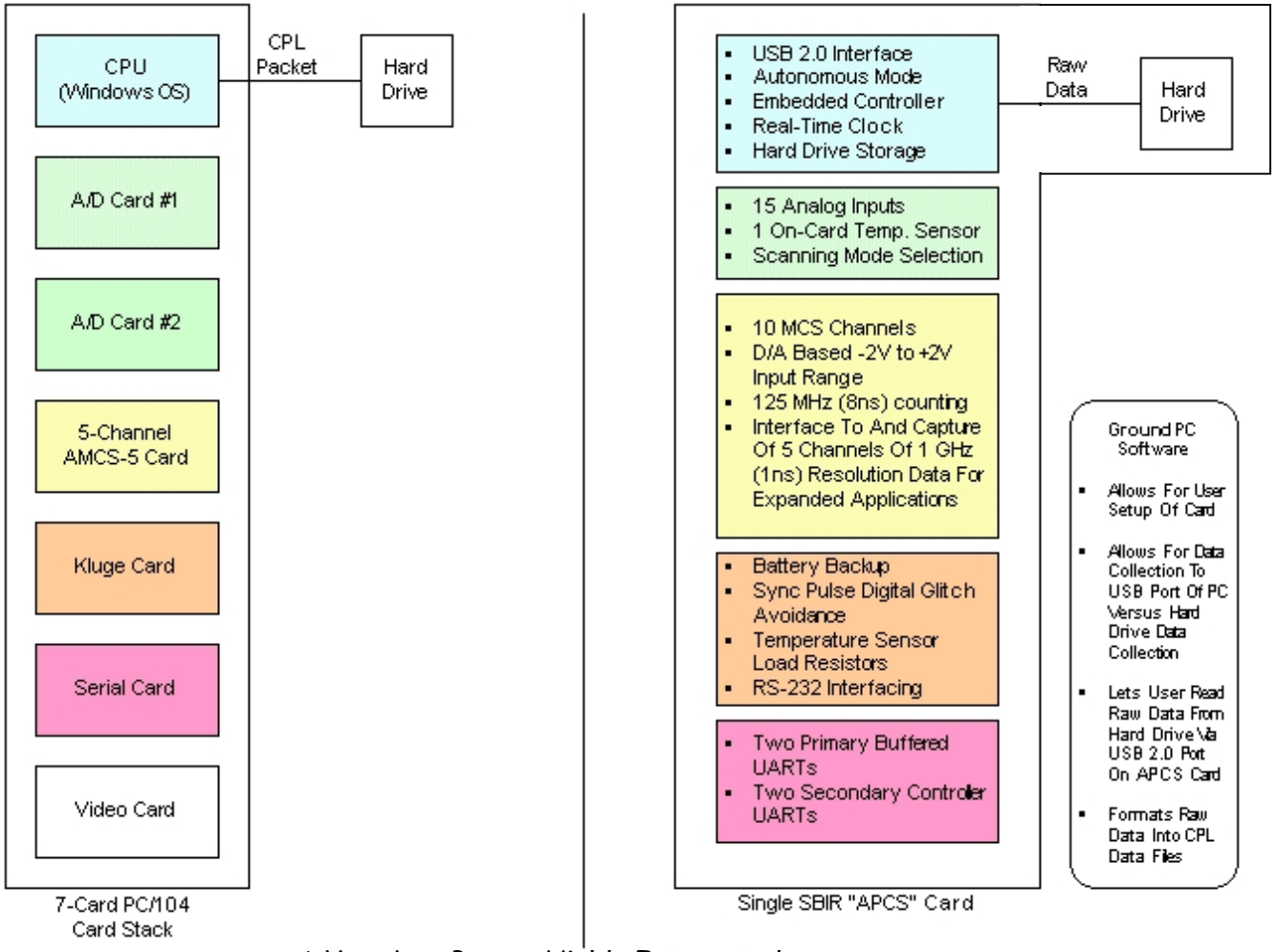
NASA Programs: Cloud Physics Lidar (CPL) – cont.

AMCS-5 based vs. APCS based CPL Data System



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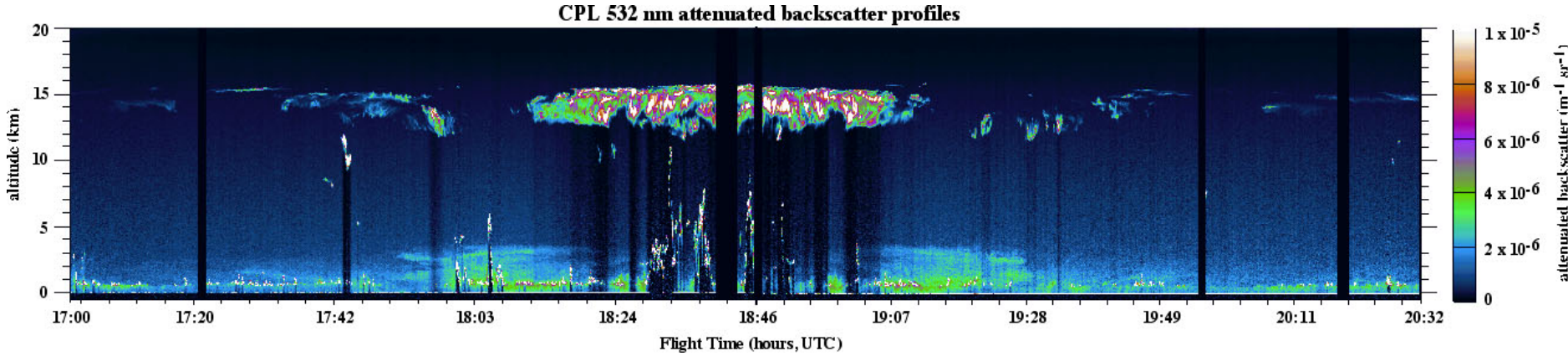
NASA Programs: Cloud Physics Lidar (CPL) – cont.



Example of CPL data obtained during CRYSTAL-FACE campaign:
This image shows profiles of attenuated backscatter obtained on July 26, 2002. This image is representative of airborne lidar data, showing cloud height and internal structure (including cirrus and subvisual cirrus, low- and mid-level clouds, and multiple cloud layers) and boundary layer aerosol. In addition, a period of elevated aerosol, known to be Saharan dust, is evident in the middle of the time period.

*Photo & Description Courtesy of Dr. Matt McGill, NASA GSFC

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NASA Programs: Micropulse Lidar (MPL)

- The Micropulse Lidar instrument is an eye-safe, ground-based lidar used to profile cloud and aerosol structure
- Laser PRF is 2.5 kHz @ 8 μJ with 523 nm detection.
- The "Type-4" data system uses the AMCS-USB card to collect the data
  - FPGA is slightly modified to provide specific internal and external pulses per MPL system needs
- ASRC has delivered 15 "AMPL" (Advanced Micropulse Lidar) data systems to date; they are deployed world-wide, some operating 24 hours per day, 7 days per week.
- ASRC's data systems are part of the complete Type 4 MPL system sold by Sigma Space Corporation (www.sigmaspace.com/www/micropulselidar.htm).
- ASRC's software controls the data system, applies various algorithms to the data, and plots the data.
- The AMCS-USB USB 1.1 connection readily allows for laptop control and collection of data

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NASA Programs: Micropulse Lidar (MPL) – cont.

AMCS-USB Card

AMPL Type-4 Data System

ASRC's AMPL Software Application

Micropulse Lidar – Type 4 – Complete System

*Photo from www.sigmaspace.com

Sample MPL Data

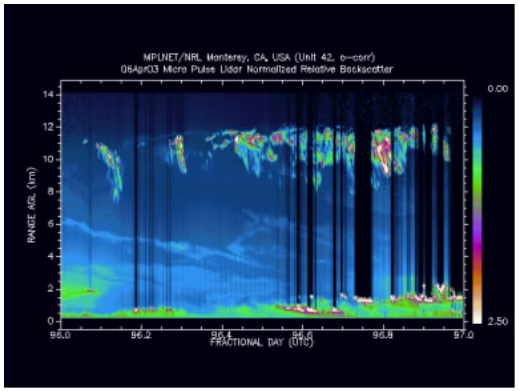

*Photo from www.sigmaspace.com

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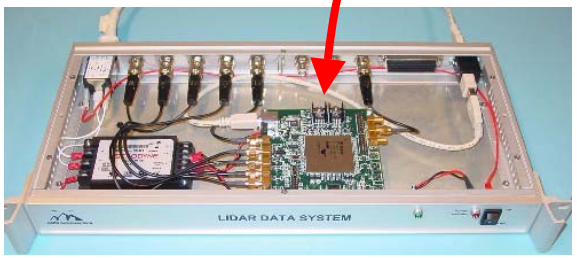
NASA Programs: Goddard Lidar Observatory for Winds (GLOW)

- The GLOW system is a mobile Doppler lidar system used to measure wind profiles (speed and direction)
- In 2002, replaced 3 large EG&G Turbo-MCS enclosures with one small rack-mountable system containing the AMCS-USB card. This resulted in great space and power savings.
- Software drivers for AMCS-USB readily substituted for the Turbo-MCS within 1 day; easy transition.
- Along with an external DC block and a signal threshold reduction (via resistor change on card), the AMCS-USB was able to reliably accept NIM signal from the GLOW discriminator.
- Furthermore, the AMCS-USB card's FPGA was customized
  - Provide 100 MHz count rate given 5 ns wide input pulses
  - Provide an "Acquire" signal output that is asserted and de-asserted based on the first/last bin. This is used for system level functions.
- Turbo MCS & AMCS-USB systems ran together in lab to validate data collection

GLOW System

*Photo from glow.gsfc.nasa.gov

AMCS-USB Card



GLOW MCS Data System

NASA Programs: GLOW – cont.

- The GLOW system using the AMCS-USB card ran successfully during the IHOP 2002 campaign (May 13 – June 25, 2002), collecting more than 240 wind profiles.
  - 10 Hz laser PRF, 10 second (100 shot) integration times, 45 meter (300 ns) bins
  - System was reported to have performed with excellent results in the field

GLOW System During IHOP

*Photo from glow.gsfc.nasa.gov

NASA Programs: Others

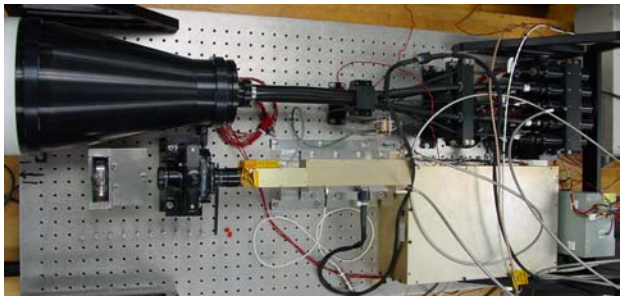
- THOR Lidar

  (Thickness from Off-beam Returns)
  - Estimates cloud thickness by measuring the halo caused by the laser into cloud
  - Uses 2 AMCS-5 PC/104 cards for a total of 10 detector channels
  - Flown in NASA P3-B aircraft

- HARLIE Lidar

  (Holographic Airborne Rotating Lidar Instrument Experiment)
  - Atmospheric & wind profiling
  - Uses AMCS-USB card

THOR Lidar in NASA GSFC Lab



HARLIE Lidar Trailer

*Photo from harlie.gsfc.nasa.gov

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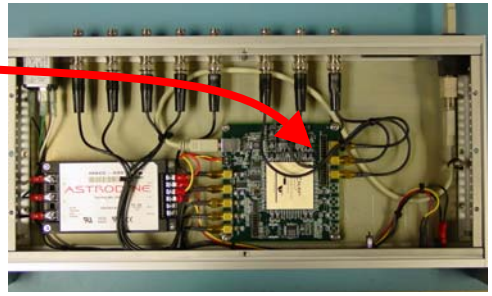
NASA Programs: Others – cont.

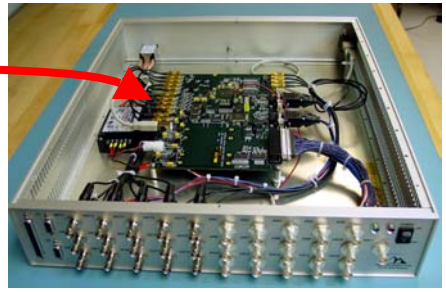
- Multichannel Doppler Wind Lidar
  - 24-detector input wind system attained by using 6 AMCS-USB cards connected via a single commerical USB hub.
  - Located in laboratory at NASA GSFC

- CO2 Testbed Lidar
  - AMCS-USB card-based system as well as APCS card-based systems delivered to project at GSFC
  - Collects data after each shot (no hardware accumulation)

AMCS-USB Card



APCS Card



- Christmas Island (Kiribati) Lidar
  - AMCS-5 card based system awaiting deployment

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Govt. / Industry / University Lidars

- In addition to supporting NASA lidar programs, the MCS cards have been commercially accepted and used by companies and institutions such as:
  - Government Institutions:
    - NOAA / Mauna Loa Observatory
    - Observatoire Cantonal de Neuchatel (ON)
    - Environment Canada – Centre for Advanced Research Experiments (CARE)
  - Universities
    - Utah State University Space Dynamics Laboratory (USU SDL)
    - Kyoto University Radio Science Center for Space and Atmosphere (RASC)
    - Montana State University – Bozeman
    - Tokyo Metropolitan University
    - University of Arizona
  - Corporate
    - Sigma Space Corporation
    - Science and Engineering Services, Inc. (SESI)
    - Battelle for Pacific Northwest National Labs (PNNL)
    - BNFL Instruments

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Non-NASA Applications - Examples

- Mauna Loa Observatory:
  - AMCS-USB based system deployed to American Samoa
- Observatoire Neuchatel:
  - AMCS-5 based system (2 cards) used in MAL-1/2 system deployed in Russian M55 Geophysica aircraft.
  - Flew in TROCCINOX (Tropical Convection, Cirrus and Nitrogen Oxides Experiment) in Brazil in Jan/Feb 2005
- Utah State University Space Dynamics Lab:
  - Aglite Lidar: agricultural productivity observations
- Batelle / PNNL:
  - Several AMCS-USB and AMCS-5 systems deployed
    - PARSL (PNNL Atmospheric Remote Sensing Laboratory) lidar
    - Sample data from MPACE (Mixed-Phase Arctic Cloud Experiment) campaign during October 2004
- Others:
  - Military – Biological aerosol detection and identification
  - Nuclear waste monitoring & barrel decommissioning

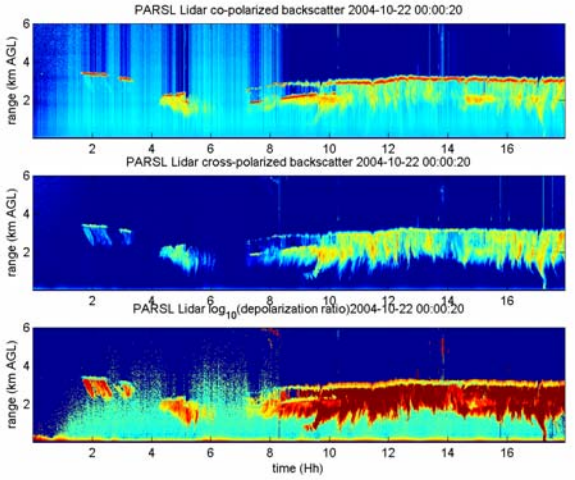

*Photo courtesy of Connor Flynn, PNNL

Current Efforts – SBIR Phase-III UAV Motivation

- NASA's ER-2 & WB-57 flights are diminishing
- NASA is favoring UAV-based instrument platforms
  - Can attain high altitudes (~65,000 feet)
  - Can sustain long-duration flights (~30 hours)
  - Lower operational costs
- Need to keep lidar instruments up-to-date and suited for UAV platforms
- ESTO's funding allows for key NASA lidar programs to continue operation in the UAV environment

Global Hawk UAV

*Photo from www.edwards.af.mil

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Current Efforts – SBIR Phase-III CPL & GLOW Migration

- The Phase-III SBIR focuses on the migration of the CPL and GLOW data systems to UAV platforms

- For UAV operation, several added functions are required
  - Single point power control
  - Real-time commanding
  - In-flight quicklook-data capability
  - UAV-specific interface support
  - Unique navigational data support
  - Ground system software

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Current Efforts – SBIR Phase-III Power Controller

- Power Controller currently assembled
  - 3U, 19" wide rack-mountable, 8" deep enclosure
  - Single master power control of all AC & DC power to CPL laser, data system, and heaters

    +28VDC @ 35A - Additional Heaters
    +28VDC @ 20A - Laser
    +28VDC @ 15A - Survival Heaters
    110VAC @ 5A - Data System
  - Industrial-grade custom circuit card for unique switching control uses a Xilinx CPLD for customized logic switching
    - Reprogrammable for future changes
    - Reusable for both CPL and GLOW platforms
  - Use of high-reliability mechanical and solid state relays and electronics
    - High Vibration
    - Wide Operational Temperature Range
    - Low Pressure (~ 1 psi)
    - No Significant Airflow at Altitude
  - Backward compatible with existing connections
  - Mode and Enable switches for use in flight or ground settings
  - Serial navigation data simulator pass-through connections
  - Indicator LEDs

Power Controller

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Current Efforts – SBIR Phase-III APCS Hardware & Firmware Updates

- APCS card utilizes microcontroller and FPGA
  - Xilinx Virtex-II FPGA performs data collection (MCS, serial ports, A/D)
  - Microcontroller performs setup and data packet formation as well as hard drive storage and USB 2.0 transfer functions
- Both microcontroller and FPGA are in-system programmable
- APCS card was designed with general purpose interfaces
  - Serial ports, discrete I/O, and IDE hard drive
  - Allows for migration to other interfaces with in-line COTS devices (i.e. RS-422, ARINC nav data, Ethernet, etc.)
- For UAV, updates include:
  - Real-time commanding
  - Quicklook data options (basic quicklook already implemented)
  - Nav data mods such as ARINC or additional GPS support
  - Ground system control and command software
  - Specific aircraft payload interfacing

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TRLs - Status

- No UAV flights for CPL (or GLOW) are scheduled in 2005
- CPL scheduled to fly in December 2005
  - Demonstrate Power Controller
  - Demonstrate Quicklook data features
  - Demonstrate a subset of firmware updates
- Technology Readiness Level (TRL) = 4
  {stand-alone APCS card demonstrated in a laboratory environment}
- Aim to attain TRL = 6
  {system prototype demonstration in a relevant environment}
- Hope to fly system on UAV in 2006

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Future Work & Goals

- SBIR Phase-III will continue throughout 2005

- Items to complete include:
  - Laboratory testing and in-flight evaluation of Power Controller
  - Delivery of second CPL Data System
  - GLOW-specific modifications to begin UAV-based GLOW migration

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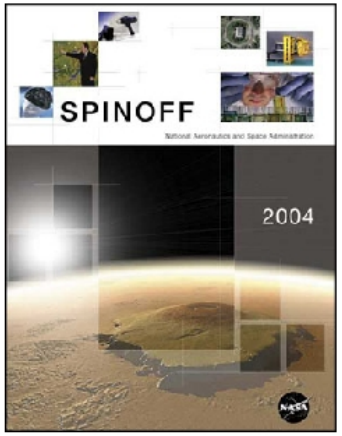
NASA Recognition

ASRC Aerospace's efforts resulting from the Phase-I and Phase-II SBIR programs have been recognized by NASA

- SBIR Success Story Website
  http://sbir.gsfc.nasa.gov/SBIR/successes/ss/5-090text.html

- NASA Tech Briefs, Vol. 28, No. 7 (July 2004)

- Spinoff 2004
  - The Spinoff publication highlights the benefits resulting from Industry & NASA partnerships



- NASA Technology Transfer Office
  - The NASA Technology Transfer Office has been pleased with our work due to the "spin-ins" and "spin-offs" from the SBIR deliverables